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⑰ **Method for the production of polymethacrylates.**

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Description

This invention relates to an improved method for the production of polymethacrylates. More particularly, it relates to a method for the production of polymethacrylates which can give a molded product having excellent mold release characteristics when polymerized and molded in a mold, which comprises rapidly polymerizing an unsaturated monomer selected from a methacrylate or a monomer mixture comprising predominantly a methacrylate which may partly contain a polymer of the monomer in the presence of a specific polymerization initiator and polymerization accelerator.

It is disclosed in West German Patent Publication No. 1,146,254 that an unsaturated monomer such as methyl methacrylate is comparatively rapidly polymerized in the presence of an alkylacyl peroxide, a compound containing sulfur in the molecule, a halogen-containing compound (e.g. tertiary amine hydrochloride, etc.) and, optionally, a heavy metal-containing compound at room temperature.

According to the polymerization method of the above West German patent publication, the polymerization activity is comparatively high, but when the polymerization and molding are carried out within a mold, the resulting molded product of the polymer has low mold release characteristics and hence the productivity is low.

US—A—2 946 770 discloses processes for the polymerization of organic compounds having carbon to carbon double bonds such as styrene and its derivatives, acrylic and methacrylic acids and esters thereof. These compounds can be polymerised in bulk. The specification discloses that the polymerization of such organic compounds can be considerably accelerated and improved if organic onium compounds are employed as polymerization accelerators. Various inorganic and organic compounds are disclosed and the salts of quaternary ammonium bases are said to be particularly effective. The polymerization may be carried out in the presence of a catalytic amount of a heavy metal polymerization accelerating compound consisting of copper or iron salts.

Further, US—A—3,565,822 is concerned with the polymerization of methacrylic esters without the use of conventional free radical catalysts. The invention is particularly concerned with a methacrylate ester polymerization system which is comprised of a methacrylate ester peroxide or a combination of a methacrylate ester and oxygen which can provide a methacrylate ester oxide, and an accelerator therefor, namely an oxidizable sulfur compound, copper, an organic amine or amine salt, and a salt of either cerium, manganese, cobalt, nickel, mercury, germanium, tin or antimony.

EP—A—0 231 395 (a document published after the filing date of this application) describes and claims a process for preparing a methacrylate polymer comprising polymerizing a methacrylate ester or a mixture of unsaturated monomers comprising the methacrylate esters as a main component in the presence of (1) a hydroperoxide polymerization initiator, (2) a reductant containing sulfur in a molecule, (3) a hydrogen halogenide salt of amine or a quaternary ammonium halogenide and (4) a copper-containing compound; it may be noted that this prior application is concerned with the use of hydroperoxide polymerization initiators in contrast with peroxyester polymerization initiators as required in the present invention.

We have developed an improved method for the production of polymethacrylates which can produce a molded product having excellent mold release characteristics when polymerized and molded in a mold and have found that the desired polymethacrylates can be prepared by polymerizing an unsaturated monomer selected from a methacrylate or a monomer mixture comprising predominantly a methacrylate which may partially contain a polymer of the monomer in the presence of a specific polymerization initiator and polymerization accelerator.

It would be desirable to provide an improved method for the production of polymethacrylates having excellent moldability and, further, to provide a rapid polymerization method for the production of the polymethacrylates having the desired properties.

Accordingly, the present invention provides for the production of polymethacrylates by a bulk polymerization in a mold, which comprises polymerizing 100 parts by weight of an unsaturated monomer which is either a methacrylate or a monomer mixture comprising predominantly a methacrylate which may partially contain a polymer of the monomer in the presence of 0.1 to 5 parts by weight of a peroxyester polymerization initiator, 0.1 to 5 parts by weight of a reducing compound containing sulfur in the molecule thereof, 0.005 to 10 ppm (in copper weight based on the weight of the starting unsaturated monomer) of a copper-containing compound which is soluble in the monomer, and 0.005 to 1 part by weight of a tertiary amine hydrohalogenate of the formula [I]:



wherein X is a halogen atom, R_1 , R_2 and R_3 are the same or different and are each an alkyl group containing 1 to 16 carbon atoms, and the total number of atoms in these R_1 , R_2 and R_3 groups (represented by C_1 , C_2 and C_3 , respectively) is in the range of the formula: $10 \leq (C_1 + C_2 + C_3) \leq 42$, or a quaternary ammonium halide of the formula [II]:



wherein X is a halogen atom, R_4 , R_5 , R_6 and R_7 are the same or different and are each an alkyl group containing 1 to 16 carbon atoms, and the total number of carbon atoms in groups R_4 , R_5 , R_6 and R_7 (represented by C_4 , C_5 , C_6 and C_7 respectively) is in the range of the formula:

$$11 \leq (C_4 + C_5 + C_6 + C_7) \leq 43.$$

The methacrylates used in this invention include esters of methacrylic acid with monohydric, dihydric or polyhydric alcohols containing 1 to 25 carbon atoms or phenols. Suitable examples of the alcohols and phenols are methanol, ethanol, isopropanol, t-butanol, sec-butanol, phenol, cyclohexanol, 4-methylcyclohexanol, 1-cyclohexylethanol, 1-adamantanol, 2-adamantanol, 3-methyl-1-adamantanol, 3,5-dimethyl-1-adamantanol, 3-ethyladamantanol, 3-methyl-5-ethyl-1-adamantanol, 3,5,8-triethyl-1-adamantanol, 3,5-dimethyl-8-ethyl-1-adamantanol, octahydro-4,7-menthanoinden-5-ol, octahydro-4,7-menthanoinden-1-ylmethanol, p-menthanol-8, p-menthanol-2,3-dihydroxy-2,6,6-trimethylbicyclo[3.1.1]heptane, 3,7,7-trimethyl-4-hydroxybicyclo[4.1.0]heptane, borneol, isoborneol, 2-methylcamphanol, phenethyl alcohol, l-menthanol, 2,2,5-trimethylcyclohexanol, ethylene glycol, diethylene glycol, tetraethylene glycol, nonaethylene glycol, tetradecaethylene glycol, bisphenol A, trimethylolpropane and pentaerythritol.

The methacrylates may be used alone, but other copolymerizable unsaturated monomers may optionally be used with it in order to improve the polymerization activity in the polymerization step, or to improve the properties of the polymer. Suitable examples of the copolymerizable unsaturated monomer are, for example, acrylates, such as methyl acrylate, ethyl acrylate, butyl acrylate, propyl acrylate, phenyl acrylate, cyclohexyl acrylate; aromatic vinyl compounds, such as styrene, p-methylstyrene, α -methylstyrene; acrylic acid; methacrylic acid; malic anhydride; or acrylonitrile. These copolymerizable unsaturated monomers may be used in an amount of not more than 50 parts by weight, preferably not more than 30 parts by weight, to 100 parts by weight of the methacrylate. When the copolymerizable monomer is used in an amount of over the above range, the original properties of the polymethacrylate, such as gloss, weatherability and hardness are undesirably deteriorated.

The methacrylate or mixture thereof with other copolymerizable unsaturated monomers may be used in the form of a pure monomer, but preferably it is used in the form of so-called syrup of the monomer which contains in part a polymer of the monomer in order to improve the polymerization activity or in view of easy handling thereof. The syrup preferably has a polymer content of 3 to 40% by weight, the syrup has unfavorably too high viscosity and hence is difficult to handle. The syrup can be prepared by known methods, for example, by partly polymerizing the monomer in the presence of a polymerization initiator and terminating the polymerization reaction at a suitable conversion degree, or by dissolving the prescribed amount of polymer in the monomer.

The radical polymerization initiator used in this invention is peroxyester, in view of high polymerization activity. Suitable examples of the peroxyesters are, t-butyl peroxy-3,5,5-trimethylhexanoate, t-butyl peroxyacetate and t-butyl peroxybenzoate.

The initiator is used in an amount of 0.1 to 5 parts by weight to 100 parts by weight of the unsaturated monomer or a syrup thereof. When the amount of the initiator is less than 0.1 part by weight, the polymerization does not sufficiently proceed. On the other hand, when the amount of the initiator is over 5 parts by weight, it is difficult to control the polymerization reaction, and hence, the resulting polymer shows unfavorably lower resistance to weather and heat.

The reducing compound containing sulfur in the molecule thereof used in this invention is a compound which forms a Redox system with the radical polymerization initiator, and includes divalent or tetravalent sulfur compounds selected from sulfinic acid esters, thioureas and mercaptans. Suitable examples of the sulfur-containing reducing compound are methyl p-toluenesulfinate, ethyl p-toluenesulfinate, tetramethylthiourea, dibutylthiourea, laurylmercaptan, t-dodecylmercaptan, octylmercaptan, butylmercaptan, 2-ethylhexyl thioglycolate, pentaerythritol tetrathioglycolate, glycol dimercaptoacetate, 2-mercaptoethanol and esters thereof, β -mercaptopropionic acid and esters thereof. The sulfur-containing reducing compound is used in an amount of 0.1 to 5 parts by weight to 100 parts by weight of the unsaturated monomer or a syrup thereof. When the amount of the sulfur-containing reducing compound is less than 0.1 part by weight, the polymerization reaction proceeds at a slower rate, and on the other hand, when it is more than 5 parts by weight, the resulting polymer is unfavorably coloured and shows lower mechanical properties.

The copper-containing compound used in this invention is a catalyst for decomposing the polymerization initiator, and includes copper salts of organic acids and copper-containing complexes which are soluble in the monomers such as methacrylate, for example, copper naphthenate and copper acetylacetonate. These copper-containing compounds are used in an amount of 0.005 to 10 ppm

(calculated in copper weight), preferably 0.1 to 5 ppm, based on the weight of the unsaturated monomer or syrup thereof. When the amount of the compound is less than 0.005 ppm, the polymerization reaction proceeds at a slower rate and the polymerization time is not fixed. On the other hand, when the amount of the compound is over 10 ppm, the polymerization initiator is unfavorably deactivated and hence the polymerization reaction is inhibited.

The tertiary amine hydrohalogenate of the formula [I] or quaternary ammonium halide of the formula [II] used in this invention is effective for accelerating stably the polymerization reaction and also effective for releasing the molded product from the mold. Suitable examples thereof are, a hydrochloride or hydrobromide of a tertiary amine such as tributylamine, triethylamine, trihexylamine, trioctylamine, tricyclohexylamine, trilaurylamine, trimyristylamine, tridecylamine, dimethyloctylamine, dimethylaurylamine, dimethyldecylamine and dimethylmyristylamine; quaternary ammonium halides, such as trioctylmethylammonium chloride, tridecylmethylammonium chloride, trilaurylmethylammonium chloride and trimyristylmethylammonium chloride. In these compounds, the alkyl group bound to the nitrogen atom thereof has from 1 to 16 carbon atoms, and the total number of carbons is in the range of 10 to 42 in case of the tertiary amine salts and 11 to 43 in case of the quaternary ammonium salts. When the total carbon numbers are less than the above ranges, the compounds have less solubility in the unsaturated monomer such as methacrylates and the molded products of the polymer show lower mold release characteristics. On the other hand, when the total carbon number are more than the above limits, the compounds also have less solubility in the unsaturated monomer such as methacrylates and the polymer shows unfavorably less heat resistance. When at least one of the alkyl groups has 5 or more carbon atoms the molded product of the resulting polymer has particularly excellent mold release characteristics. On the other hand, when at least one of the alkyl groups has 17 or more carbon atoms, the compound has unfavorably lower solubility in the unsaturated monomer such as methacrylates. These compounds are used in an amount of 0.005 to 1 part by weight, preferably 0.01 to 0.5 part by weight, to 100 parts by weight of the unsaturated monomer or syrup thereof. When the amount of the above compounds is less than 0.005 part by weight or more than 1 part by weight, the polymerization reaction proceeds unfavorably at a slower rate.

The polymerization reaction of this invention is carried out by a bulk polymerization method where a mold is used. A liquid composition is prepared by dissolving a radical polymerization initiator, a sulfur-containing reducing compound, a copper-containing compound and the specific tertiary amine hydrohalogenate or quaternary ammonium halide in the monomer such as a methacrylate or a syrup thereof, and the liquid composition thus prepared is poured into a mold, followed by subjection to the polymerization reaction and molding. In the polymerization within a mold, each component may be mixed individually and poured into the mold, but owing to the high polymerization reactivity, it is sometimes very difficult to mix them uniformly. Accordingly, in the preferred embodiment, the polymerization initiator and the reducing compound and copper-containing compound are separately dissolved in a part of the monomer or syrup thereof, and they are mixed in each prescribed amount immediately before subjection to the polymerization reaction.

The method of this invention may be carried out at room temperature, but is preferably carried out at an elevated temperature such as 50°C or higher in order to accelerate the polymerization. In such a case, the monomer, polymerization initiator and other ingredients are mixed and poured into the mold and then the temperature in the mold is raised to 50°C or higher, or alternatively, the temperature in the mold is raised to 50°C or higher, and then the monomer, polymerization initiator and other ingredients are mixed and poured into the mold, followed by the polymerization.

Because the molded product of the polymer of this invention has excellent mold release characteristics, the product may be released from the mold by cooling it after the polymerization reaction, but it may be released from the mold without cooling thereof.

The mold used in this invention is preferably a metallic mold in view of the strength and ease of cooling.

The method of this invention can be applied to the production of various formed products of polymethacrylate. That is, by varying the shape of the mold which is used in the polymerization, there can be obtained various shaped products.

This method is particularly suitable for the production of optical parts because the polymer thus prepared has much less internal strain. Such optical parts include conventional lenses, Fresnel lenses, optical recording disc media, prisms and mirrors. In this method, the face of the mold can be transferred precisely, and hence, it is particularly suitable for the production of Fresnel lenses which requires precise shape. Moreover, this method can easily give large scale shaped products, and hence, is also suitable for the production of automobile parts such as windcreens, windows, rear windows, and, furthermore, signs, water tank panels and bathtubs.

According to this invention, the desired polymethacrylates can be produced having less coloration and excellent weatherability in a very short period of time. The starting monomer and other ingredients are added to a mold and therein subjected to polymerization and molding, in which the molded product can easily be released from the mold.

This invention is illustrated by the following Examples but should not be construed to be limited thereto.

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Examples 1 to 5 and Comparative Examples 1 to 2

Preparation of starting syrup of methyl methacrylate:

A 10 liter stainless sealed vessel is charged with methyl methacrylate (4 kg) and polymethyl methacrylate (SUMIPEX® BMH, manufactured by Sumitomo Chemical Co., Ltd., 1 kg), which is dissolved at 60°C for 5 hours to give the desired starting syrup having a polymer content of 20% by weight and a viscosity of 1 poise (1dPas).

Polymerization and molding:

In the starting syrup (100 g) are dissolved t-butyl peroxybenzoate (1 g), glycol dimercaptoacetate (0.7 g), a 1% solution (0.04 g) of copper naphthenate (Cu content 10%) in methyl methacrylate and an amine hydrochloride (0.09 g) as shown in Table 1. When the amine hydrochloride is not dissolved in the starting syrup of methyl methacrylate, it is used in a 8% solution in diethylene glycol.

The resulting solution is poured within the mold (150 × 150 × 3 mm, made of metal, the inner surface being coated with SUS), and then subjected to polymerization by dipping into a water bath at 85°C. After 5 to 8 minutes from initiation of the reaction, the temperature rises to a maximum due to reaction heat, and then, the polymerization reaction is almost completed. The temperature, at which the product can be released from the mold immediately after the polymerization reaction is measured. The results are shown in Table 1.

TABLE 1

Ex No.	Amine hydrochloride	Mold release* characteristics
Ex. 1	Triamylamine hydrochloride	Δ
Ex. 2	Trioctylamine hydrochloride	○
Ex. 3	Dimethyloctylamine hydrochloride	○
Ex. 4	Dimethylmyristylamine hydrochloride	○
Ex. 5	Dimethyldecylamine hydrochloride	○
Comp. Ex. 1	Dibutylamine hydrochloride	X
Comp. Ex. 2	Phenethyldibutylamine hydrochloride	X

*) Mold release characteristics:

○: Releasable at 60°C or higher

Δ: Releasable at from 40°C to 60°C

X: Impossible to release at 40°C or higher.

Example 6

In the same starting syrup (100 g) as used in Example 1 are dissolved t-butyl peroxybenzoate (1 g), glycol dimercaptoacetate (0.7 g), a 1% solution (0.04 g) of copper naphthenate (Cu content 10%) in methyl methacrylate and trioctylmethylammonium chloride (0.1 g), and the resulting solution is poured into the same mold (150 × 150 × 3 mm) as used in Example 1, and then subjected to polymerization by dipping into a water bath at 85°C 8 minutes after initiation of the reaction, the temperature rises to a maximum due to the reaction heat, and then, the polymerization reaction is almost completed. After the polymerization, the molded product can be released from the mold even at 80°C. Thus, the molded product shows excellent mold release characteristics.

Claims

1. A method for the production of polymethacrylates by a bulk polymerization in a mold, which comprises polymerizing 100 parts by weight of an unsaturated monomer which is either a methacrylate or a monomer mixture comprising predominantly a methacrylate which may partially contain a polymer of the monomer in the presence of 0.1 to 5 parts by weight of a peroxyester polymerization initiator, 0.1 to 5 parts by weight of a reducing compound containing sulfur in the molecule thereof, 0.005 to 10 ppm (in copper weight based on the weight of the starting unsaturated monomer) of a copper-containing compound which is soluble in the monomer, and 0.005 to 1 part by weight of a tertiary amine hydrohalogenate of the formula [I]:

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wherein X is a halogen atom, R_1 , R_2 and R_3 are the same or different and are each an alkyl group containing 1 to 16 carbon atoms, and the total number of atoms in these R_1 , R_2 and R_3 groups (represented by C_1 , C_2 and C_3 , respectively) is in the range of the formula:

$$10 \leq (C_1 + C_2 + C_3) \leq 42,$$

or a quaternary ammonium halide of the formula (II):



wherein X is a halogen atom, R_4 , R_5 , R_6 and R_7 are the same or different and are each an alkyl group containing 1 to 16 carbon atoms, and the total number of carbon atoms in groups R_4 , R_5 , R_6 and R_7 (represented by C_4 , C_5 , C_6 and C_7 respectively) is in the range of the formula:

$$11 \leq (C_4 + C_5 + C_6 + C_7) \leq 43.$$

2. A method as claimed in claim 1, wherein the unsaturated monomer is a syrup of an unsaturated monomer which is a methacrylate or a monomer mixture comprising predominantly a methacrylate, said syrup containing 3—40% by weight of the polymer of the monomer.

3. A method as claimed in any one of the preceding claims wherein the methacrylate is an ester of methacrylic acid with a monohydric dihydric or polyhydric alcohol having 1 to 25 carbon atoms, or phenol.

4. A method as claimed in any one of the preceding claims wherein the sulfur-containing reducing compound is a sulfinic acid ester, a thiourea or a mercaptan.

5. A method as claimed in any one of the preceding claims wherein the polymerization is carried out at at least 50°C.

6. A method as claimed in any one of the preceding claims wherein the resulting polymer is shaped in the mold to form an optical product such as a lens, a Fresnel lens, optical recording disc media, a prism or a mirror.

Patentansprüche

1. Verfahren zur Herstellung von Polymethacrylaten durch Massepolymerisation in einer Form, welches die Polymerisation von 100 Gew.-Teilen eines ungesättigten Monomers umfaßt, welches entweder ein Methacrylat oder ein Monomergemisch ist, das überwiegend ein Methacrylat enthält, das teilweise ein Polymer des Monomers enthalten kann, in Gegenwart von 0,1 bis 5 Gew.-Teilen eines Peroxyester-Polymerisations-Initiators, 0,1 bis 5 Gew.-Teilen einer reduzierenden Verbindung, die im Molekül Schwefel enthält, 0,005 bis 10 T.p.M. (des Kupfergewichts in Bezug auf das Ausgangsgewicht des ungesättigten Monomers) einer kupferhaltigen Verbindung, welche im Monomer löslich ist, und von 0,005 bis 1 Gew.-Teilen eines halogenierten tertiären Amins der Formel (I)



in der X ein Halogenatom bedeutet, R_1 , R_2 und R_3 , die gleich oder verschieden sind, jeweils einen Alkylrest mit 1 bis 16 Kohlenstoffatomen bedeuten, und die Gesamtatomzahl dieser Reste R_1 , R_2 und R_3 (durch C_1 , C_2 bzw. C_3 dargestellt), im Bereich der Formel:

$$10 \leq (C_1 + C_2 + C_3) \leq 42$$

liegt, oder eines quaternären Ammoniumhalogenides der Formel (II)

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in der X ein Halogenatom bedeutet, und R_4 , R_5 , R_6 und R_7 , die gleich oder verschieden sind, jeweils eine Alkylrest mit 1 bis 16 Kohlenstoffatomen bedeuten, und die Gesamtkohlenstoffatomzahl in den Resten R_4 , R_5 , R_6 und R_7 (durch C_4 , C_5 , C_6 bzw. C_7 dargestellt), im Bereich der Formel

$$11 \leq (C_4 + C_5 + C_6 + C_7) \leq 43 \text{ liegt.}$$

2. Verfahren nach Anspruch 1, in dem das ungesättigte Monomer ein Sirup eines ungesättigten Monomers ist, welches ein Methacrylat oder ein Monomergemisch, das überwiegend ein Methacrylat umfaßt, ist, wobei der Sirup 3 bis 40 Gew.-% des Polymers des Monomers enthält.

3. Verfahren nach einem der vorangehenden Ansprüche, in dem das Methacrylat ein Ester von Methacrylsäure mit einem Mono-, Di- oder Polyalkohol, der 1 bis 25 Kohlenstoffatome besitzt, oder ein Phenol ist.

4. Verfahren nach einem der vorangehenden Ansprüche, in dem die schwefelhaltige reduzierende Verbindung ein Sulfinsäureester, ein Thioharnstoff oder ein Mercaptan ist.

5. Verfahren nach einem der vorangehenden Ansprüche, in dem die Polymerisation bei mindestens 50°C durchgeführt wird.

6. Verfahren nach einem der vorangehenden Ansprüche, in dem das erhaltene Polymer in der Form zu einem optischen Erzeugnis, wie eine Linse, eine Fresnel-Linse, optisches Speicherplattenmaterial, Prisma oder Spiegel, geformt wird.

Revendications

1. Un procédé pour la fabrication de polyméthacrylates par polymérisation en masse dans un moule, qui consiste à polymériser 100 parties en poids d'un monomère insaturé qui est soit un méthacrylate, soit un mélange de monomères comprenant principalement un méthacrylate qui peut contenir partiellement un polymère du monomère en présence de 0,1 à 5 parties en poids d'un inducteur de polymérisation du type peroxyester, 0,1 à 5 parties en poids d'un composé réducteur contenant du soufre dans sa molécule, 0,005 à 10 ppm (en poids de cuivre par rapport au poids du monomère insaturé de départ) d'un composé contenant du cuivre qui est soluble dans la monomère et 0,005 à 1 partie en poids d'un halohydrate d'amine tertiaire de formule (I):



dans laquelle X est un atome d'halogène, R_1 , R_2 et R_3 sont identiques ou différents et représentent chacun un groupe alkyle en C_1-C_{16} et le total des nombres d'atomes de carbone dans ces groupes R_1 , R_2 et R_3 (représentés par C_1 , C_2 et C_3 , respectivement) est dans l'intervalle représenté par la formule:

$$10 \leq (C_1 + C_2 + C_3) \leq 42,$$

ou d'un halogénure d'ammonium quaternaire de formule (II):



dans laquelle X est un atome d'halogène, R_4 , R_5 , R_6 et R_7 sont identiques ou différents et représentent chacun un groupe alkyle en C_1-C_{16} et le total des nombres d'atomes de carbone dans ces groupes R_4 , R_5 , R_6 et R_7 (représentés par C_4 , C_5 , C_6 et C_7 respectivement) est dans l'intervalle représenté par la formule:

$$11 \leq (C_4 + C_5 + C_6 + C_7) \leq 43.$$

2. Un procédé selon la revendication 1, dans lequel le monomère insaturé est un sirop d'un monomère insaturé qui est un méthacrylate ou un mélange de monomères comprenant principalement un

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méthacrylate, ledit sirop contenant 3—40% en poids du polymère du monomère.

3. Un procédé selon l'une quelconque des revendications précédentes, dans lequel le méthacrylate est un ester de l'acide méthacrylique avec un monoalcool, un dialcool ou un polyalcool en C_1 — C_{25} ou un phénol.

5 4. Un procédé selon l'une quelconque des revendications précédentes, dans lequel le composé réducteur soufré est un ester d'acide sulfinique, une thiourée ou un mercaptan.

5. Un procédé selon l'une quelconque des revendications précédentes, dans lequel la polymérisation est mise en oeuvre à au moins 50°C.

10 6. Un procédé selon l'une quelconque des revendications précédentes, dans lequel le polymère résultant est moulé dans le moule pour former un produit optique tel qu'une lentille, une lentille de Fresnel, un milieu d'enregistrement optique sur disques, un prisme ou un miroir.

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